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AEROSOL FILTER LOADING DATA FOR A SIMULATED JET ENGINE TEST CELL AEROSOL

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DALE A. LUNDGREN

ENVIRONMENTAL ENGINEERING CONSULTANTS

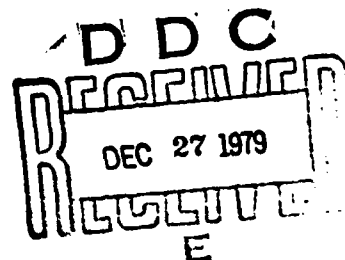
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Air Force routinely tests turbine engines in fixed test cells, some of which have been cited by state pollution control officials for violations of opacity regulations. A previous theoretical study, CEEDO-TR-78-53, predicted that relatively low efficiency and low cost techniques could bring jet engine test cells into compliance with air pollution regulations. The system proposed included a water cooling spray and a mist eliminator followed by a medium efficiency, high velocity, throw-away type glass filter media. (Continued on reverse) | | |

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The most serious limitation of high velocity filtration is the aerosol mass loading and the potential for rapid pressure drop build up across the filter. Since filter loading characteristics could not be theoretically predicted, the objective of this follow-on work was to experimentally test and report the filter loading characteristics of glass fiber filters for possible application to jet engine test cell exhaust plume opacity control.

Two types of glass fiber media were tested: (1) two different medium efficiency pre-filter media, and (2) two different high efficiency final filter media. All media were tested at a face velocity of 3 m/sec and some at 1.5 and 4.5 m/sec using a simulated jet engine test cell aerosol produced by burning #2 fuel oil in a fuel rich air stream to produce a carbon aerosol of $\sim 5+ \text{ mg/M}^3$ concentration and having $\sim 80+$ percent of the aerosol mass in the submicrometer ($<1\mu\text{m}$) diameter size range.

Test data show that the two final filter media (noted as types III and IV) load rapidly and are therefore not recommended because of a rapid increase in pressure drop. Various combinations of prefilter media (noted as types I and II) and final filter media (types III and IV) are also unsuitable for the same reason. Several tests were run on the filter media combination considered to have the best aerosol loading characteristics: this consisted of two layers of media I. Tests were run on four separate samples of media I to provide data for statistical analysis of test result variability. Even though a much lower pressure drop was noted with this configuration, it was considered unacceptable because the filters would require daily replacement.

A large reduction in filter pressure drop also resulted from water spray cleaning of the filter media and this technique may be promising for significantly extending filter life.

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PREFACE

This test data on filter loading characteristics was obtained to enable the development of design criteria for a cost effective opacity reduction system for a jet engine test cell. The work was performed by Dr. Dale A. Lundgren, Environmental Engineering Consultants, 1411 NW 50th Terrace, Gainesville, Florida 32605, under contract to HQ AFESC/RDV, Tyndall AFB, Florida 32403. Captain George Schlossnagle was the project officer.

This report has been reviewed by the Office of Information (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for public release.



GEORGE W. SCHLOSSNAGLE, Capt, USAF, BSC
Project Engineer



EMIL C. FREIN, Maj, USAF
Chief, Environics Division



MICHAEL G. MACNAUGHTON, Maj, USAF, BSC
Chief, Environmental Sciences Branch



JOSEPH S. PIZZUTO, Col, USAF, BSC
Director, Engineering and Services
Laboratory

| | |
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SECTION I

INTRODUCTION

1. BACKGROUND

The Air Force routinely tests turbine engines in fixed test cells, some of which have been cited by state pollution control officials for violations of opacity regulations. Efficient and effective, but expensive techniques exist to control these visible emissions. Compliance with opacity regulations typically requires removal of approximately 50 percent of the opacity causing aerosol from a jet engine being tested at military power. Therefore, relatively low efficiency and low cost techniques are required which effectively control test cell emissions, reduce their environmental effect, and bring them into compliance with air pollution regulations. This effort provides background data which could be used to design a low cost opacity control system for jet engine test cells.

2. OBJECTIVE

The objective of this work was to test and report the filter loading characteristics of glass fiber filters for possible application to jet engine test cell exhaust plume opacity control. The filter loading data could be used to develop design criteria for a cost effective opacity reduction system. The system recommended includes a water cooling spray and a glass fiber mesh mist eliminator followed by a medium efficiency, high velocity, throw-away glass fiber filter (and a spray cleaning arrangement).

3. SCOPE

This contractual effort provides data on four different glass fiber filters and combinations of these filters. The data consists of measurements of filter loading characteristics for a simulated jet engine test cell aerosol. The data was used to select a filter media combination which has the lowest filter pressure drop increase while achieving an aerosol opacity reduction of at least 50 percent. The filter media, which was considered best, was tested at two velocities to determine filter cleanability with water spray. The best filter media type was tested at several variations of media thickness and face velocity. The data is discussed in relation to the economic and physical feasibility of jet engine test cell aerosol filtration by glass fiber media.

SECTION II

TEST PROGRAM

1. TESTING PROCEDURE

Sheets of the filter media were obtained from Owens-Corning Fiberglas Corporation. Ten centimeter diameter circular filters were cut from each sheet for aerosol loading tests. Filter specimens were examined, marked and weighed before being mounted in specially constructed holders fitted onto standard high-volume air sampler motor-blower units. Each filter holder/blower assembly had a filter pressure tap and a calibrated blower air flow rate indicator (see Figure 1).

A total of four filter holder/blower assemblies were then mounted on top of an aerosol mixing chamber (see Figure 2). Test aerosol from an oil burner assembly and ambient air were mixed and ducted to the mixing chamber (see Figure 3). Air was drawn through the chamber by the test filter blower units at a known controlled rate. A mixing chamber sampling port was used to draw off an aerosol sample for aerosol size and mass concentration determination. The entire filter test assembly was set up and operated in a ten cubic meter steel tank test chamber.

Filter testing involved mounting the four filter test units in place, adjusting the flow rate to a predetermined value and then reading the initial filter pressure drop value. Test aerosol was fed through the four test filters for a recorded period of time and the filter pressure drops observed. Flow rates were adjusted to maintain the predetermined value and the filters loaded to a reasonably high pressure drop for a selected period of time. The final pressure drop was then recorded and the system shut down.

Upon completion of testing, the filters were removed from the holders for the final weighing. All filters were then stored in marked plastic bags.

Aerosol samples were drawn off from the mixing chamber to determine aerosol concentration and size distribution. Because of the finite time required to obtain adequate samples for aerosol analysis, together with the rapid filter loading or pressure drop increase, it was normally possible to obtain only one average aerosol measurement over a filter loading cycle.

2. TEST FILTERS

The four following glass fiber filter medias were obtained from Owens-Corning Fiberglas Corporation (OCF) and tested both individually and in various combinations:

| | | |
|-----------|---|---|
| Media I | - | OCF Type PF-3340 (a prefilter material) |
| Media II | - | OCF Type PF-3360 (a prefilter material) |
| Media III | - | OCF Type FM-004 (a final filter material) |
| Media IV | - | OCF Type FM-011 (a final filter material) |

Because of the appearance of a surface cake build up on the front face of the test filters, a fifth filter media was added and tested in combination

with one of the above. This was a standard type furnace filter media of glass fiber construction and is referred to in the report as Media V.

The physical parameters for the four OCF test media are listed in Table 1. Theoretical particle size versus collection efficiency for a clean filter media over the 0.1 to 1.0 μm diameter particle size range are shown in Figures 4, 5 and 6. Medias I and II are essentially identical in theoretical efficiency, therefore only one figure is used for these two media.

Cost of filter Medias I, II, III and IV are all approximately \$.80 per square meter and all are available from OCF.

3. TEST AEROSOL

A submicrometer carbon particle combustion aerosol was produced from a hydrocarbon fuel oil (number 2 oil). A metered quantity of fuel oil was injected and burned in the burner with a metered rate of combustion air. The air-to-fuel ratio was very rich, causing the fuel to burn to H_2O and some CO_2 with a large fraction of the carbon coming off as carbon aerosol. This carbon aerosol was then diluted with a measured volume of air to control the agglomeration of the aerosol. A schematic of the aerosol generator was shown in Figure 3.

Aerosol size distribution was measured several times using a University of Washington inertial impactor. Approximately 84 percent by weight of the aerosol was in the submicrometer size range. Aerosol concentration was measured during most tests and found to average about 6 mg/m^3 . Data from these tests is summarized in Tables 2 through 12.

4. FILTER TEST DATA

a. Individual Media Tests

Each of the four specified filter media was first tested at a specified superficial filter face velocity of 3 m/sec (10 ft/sec). Test results are shown in Table 13. Test filter IV stuck in the filter holder, therefore a reliable weight gain (mass loading) was not obtained. This test was repeated and the results are shown in Table 14 (these tests are recorded as test run 1 and 2 respectively).

b. Combination Media Tests

As specified, the following combinations of pre and final filter media were tested at a filter face velocity of 3 m/sec:

- (1) Media I plus III
- (2) Media II plus III
- (3) Media I plus IV
- (4) Media II plus IV

Test results are shown in Table 15. Because of a very rapid filter loading, tests were run on various prefilter combinations, the results being listed in Table 16. Impactor size distribution data for these runs (3 and 4 respectively) is given in Tables 2 and 3 respectively.

c. Loading Uniformity Tests

Commercial filter media are relatively nonuniform in thickness and structure. The variability in media performance was determined by simultaneous testing of four samples of Media I at 3 m/sec velocity. These four filter samples were tested over a 60-minute period, a final pressure drop recorded, and the filters removed for weighing to obtain a mass loading. Filters were then reinstalled in their respective test filter holders and a new initial pressure drop recorded at 3 m/sec velocity. Filters were loaded an additional 22 minutes at which time a final pressure drop was recorded. After removal, reweighing, and reinstallation, a final 25-minute loading test was run. Data from these test runs numbered 5, 6 and 7 is given in Table 17. Impactor size distribution data is shown in Tables 4, 5 and 6 for the three respective run numbers. Collection efficiencies were not measured but are estimated to be about 50 percent for this filter media.

d. Combination Tests on Prefilter Media

Rapid loading of prefilter/final filter media combinations and relatively high collection efficiency of the prefilter media combinations indicated that a prefilter media combination would be the optimal for the stated purpose of opacity control. Four combinations of Type I and Type II prefilters were tested in a series of three loading tests over a 4-hour period (two 60-minute tests followed by a 120-minute test). Filter pressure drop and mass loading were determined at the end of each time period as previously described. Test data for these three test runs numbered 8, 9 and 10 are shown in Table 18. Impactor size distribution data for runs 8 and 9 are given in Tables 7 and 8. Collection efficiency for these prefilter media combinations was determined in run 4 (Table 16) to be about 80 percent.

e. Filter Tests at Various Face Velocities

Various combinations of prefilters were tested and the results presented in Table 18. Results for the four combinations are not significantly different from each other. Two layers of Media I were selected as the filter combination with the best loading characteristics at various face velocities. Two layers of Media I were considered to have an ideal collection efficiency for a 50 percent or higher opacity reduction: therefore, most of the remaining tests involved two layers of Media I.

The effect of velocity on filter loading and pressure drop was shown at 1.5, 3.0 and 4.5 m/sec. Two tests were run in sequence for 60 minutes and then 30 minutes. Data from test runs 11 and 12 are shown in Table 19. Impactor size distribution for these tests are shown in Tables 9 and 10.

In most of the tests, a thin but apparent surface layer accumulated on the front face of the first filter. This layer contributes to the pressure drop. In an attempt to decrease this effect, a layer of standard furnace filter media (Media V) was placed in front of the prefilter media. The effect of this furnace filter media is inconclusive because a bonding agent or volatile coating on the furnace filter (Media V) caused a disproportionately low weight gain or mass loading on Media V. Pressure drop across the composite filter was not significantly changed.

Table 19 data does indicate a much more acceptable pressure drop at the lower test velocity. Therefore, an additional 60-minute test was run on various filter combinations at 1.5 and 3.0 m/sec. Data from this test run (13) is shown in Table 20. Impactor size distribution data was shown in Table 11. Again a layer of Media V was tested with two layers of Media I.

Two layers of Media I appear as the better filter combination but additional data was desired at 1.5 m/sec velocity on collection efficiency comparing the media at 1.5 and 3.0 m/sec. Tests 14, 15 and 16 were conducted over a longer loading period (4 hours total) to obtain initial and final collection efficiency data at the two test velocities. An additional test was also run with a layer of Media V in front of Media I. Results from this final series of tests are shown in Table 21.

f. Effect of Water Sprays on Filter Pressure Drop

The effect of water sprays (water wash) on filter pressure drop was determined for several composite samples of Media I which were loaded at test velocities of 1.5 and 3.0 m/sec. Filters loaded in the last series of tests were used for the experiment. Results of this wash test are very significant in that the filter pressure drop was reduced by approximately a factor of four. Data from these cleanability tests (recorded as run 17) are shown in Table 22. Filters were washed from the back side.

5. CONCLUSIONS

Four glass fiber filters, specified in the contract, were obtained from Owens-Corning Fiberglas Corporation. A submicrometer carbon particle combustion aerosol was produced and all filter media and media combinations were tested at a superficial filter face velocity of 3 m/sec. The best filter media combination tested consisted of two thicknesses of prefilter media. All four combinations of prefilter media were tested at 3 m/sec. One combination was tested at velocities of 1.5 m/sec, 3.0 m/sec and 4.5 m/sec. Several additional tests were then run on the filter media combination considered to have the best aerosol loading characteristics: this consisted of two layers of Media I. Tests were run on four separate samples of Media I to provide data for statistical analysis of test result variability.

As previously stated, the recommended filter media combination (having the best aerosol loading characteristics at the desired aerosol opacity reduction of greater than 50 percent) consists of two thicknesses of prefilter media. Final filter Medias III and IV were unacceptable because of very rapid increase in pressure drop with filter loading. The second recommended filter media combination is two thicknesses of Media I at a reduced filter velocity (1.5 m/sec). Both of these combinations were tested several times and the loaded filters cleanability tests were run. The reduction in pressure drop by washing was very significant. Even with the recommended filter media combination at either 3.0 or 1.5 m/sec the filter pressure drop buildup is unacceptable and without in-place cleaning would require daily replacement.

For each filter or filter combination tested the filter test velocity, initial pressure drop, final pressure drop, and filter mass loading were determined and presented. Because of very rapid filter loading it was necessary to measure an average filter efficiency during the loading test.

For the recommended filter combinations, it was possible to measure an initial filter efficiency during the first stage of loading and a final filter efficiency during the latter stage of loading.

Several plots of clean filter media particle size versus collection efficiency were presented for the tested filter medias over the 0.1 to 1.0 μm size range for filtration velocities of 0.1, 0.3, 1.0 and 3.0 m/sec. These theoretical plots together with the measured impactor mass distribution data can be used to estimate opacity reduction based upon the measured aerosol mass collection efficiency. These theoretical plots were obtained using the filter media description data given in Table 1 and the calculation procedure described by K. T. Whitby in "Calculations of the clean fractional efficiency of low media density filters," ASHRAE Journal, September, 1965.

Loading and collection efficiency data is variable because of nonuniformity of the tested filter media, nonuniformity of the aerosol generation, test method variability and human errors. Data listed in Table 17 can be used to calculate a 90 percent significance level for filter loading at low, medium and high loading levels. At the 90 percent confidence level the variation from the mean is plus or minus 20, 18 and 31 percents for these three loading levels. This is considered acceptable data for this type of test program and satisfies contractual requirements.

SECTION III

RECOMMENDATIONS

All filter media combinations are adequate or more than adequate to provide a 50 percent reduction in plume opacity. However, none of the filter media tested have adequate in-place life to be used as a cost effective opacity reduction system. A large reduction in filter pressure drop resulted from water spray cleaning of the filter media and this technique is promising for the development of a workable system. Before the design criteria for such a system could be developed it would be necessary to develop an effective filter spray wash system and test it to determine the in-place life of the recommended composite filter media. Data could not be found in the literature on which to calculate or otherwise determine the effectiveness of such a filter cleaning system or the resulting life of the filter media. An experimental effort must be undertaken to develop an effective cleaning method which will extend the useful life of the in-place filter media.

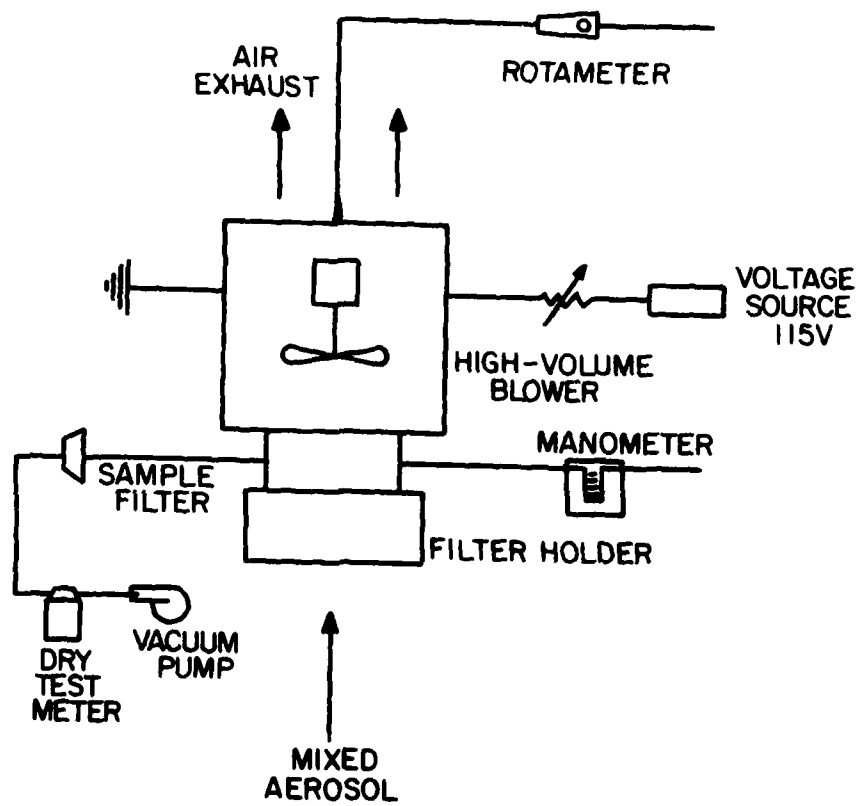


Figure 1. Filter Holder/Blower Assembly

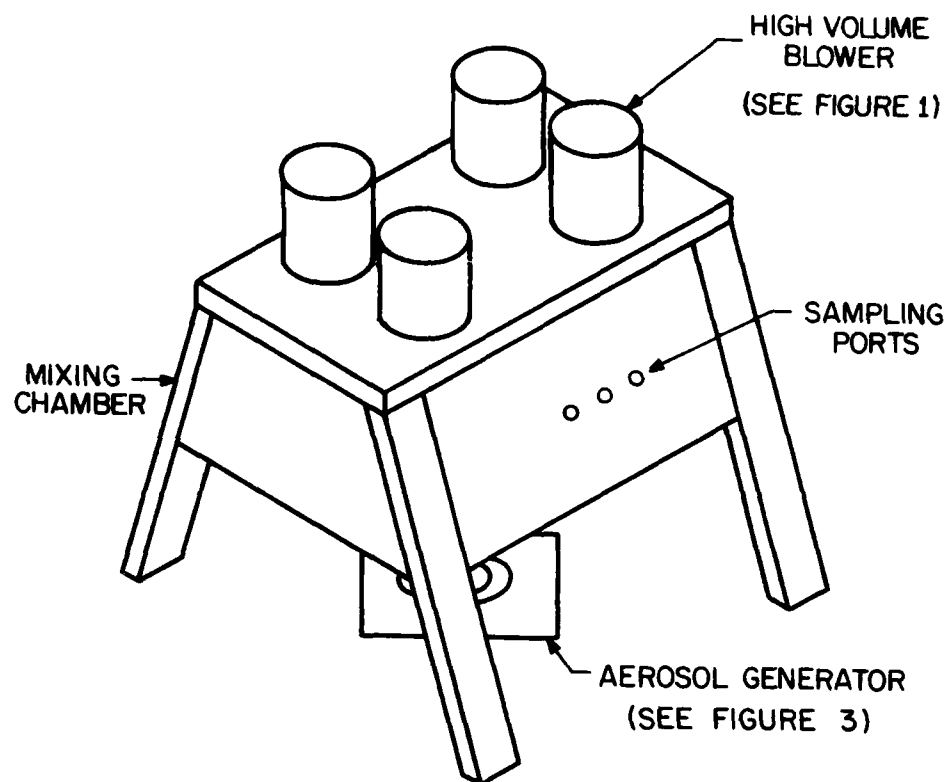


Figure 2. Filter Test Assembly

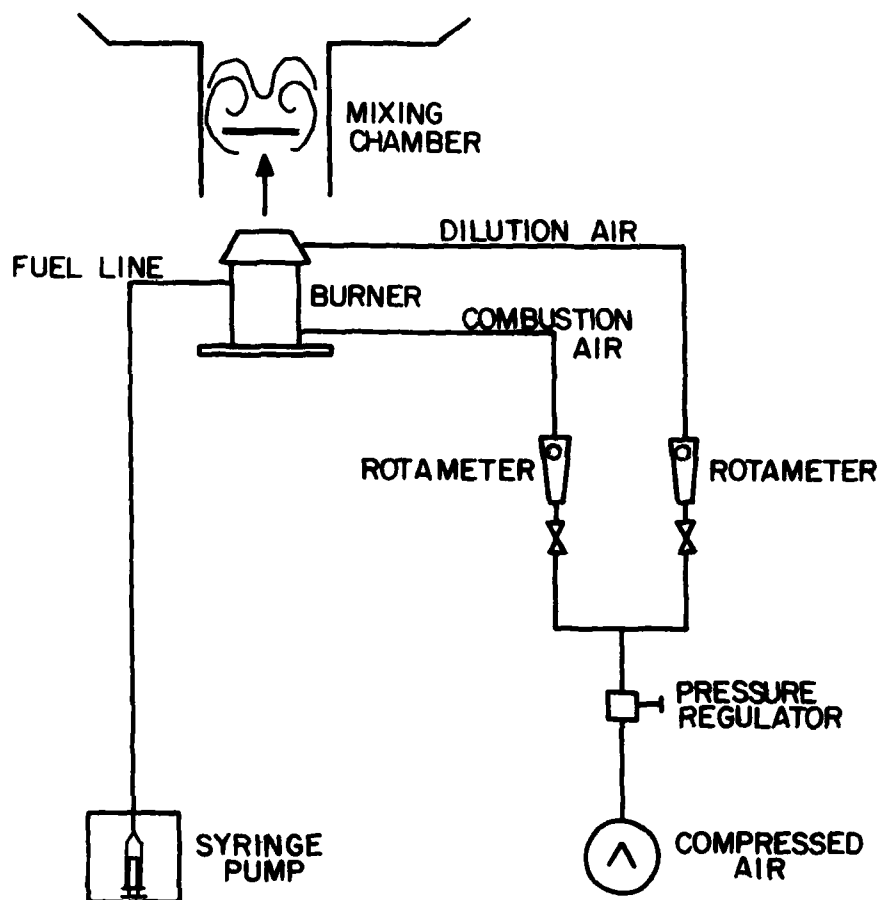


Figure 3. Aerosol Generation Assembly

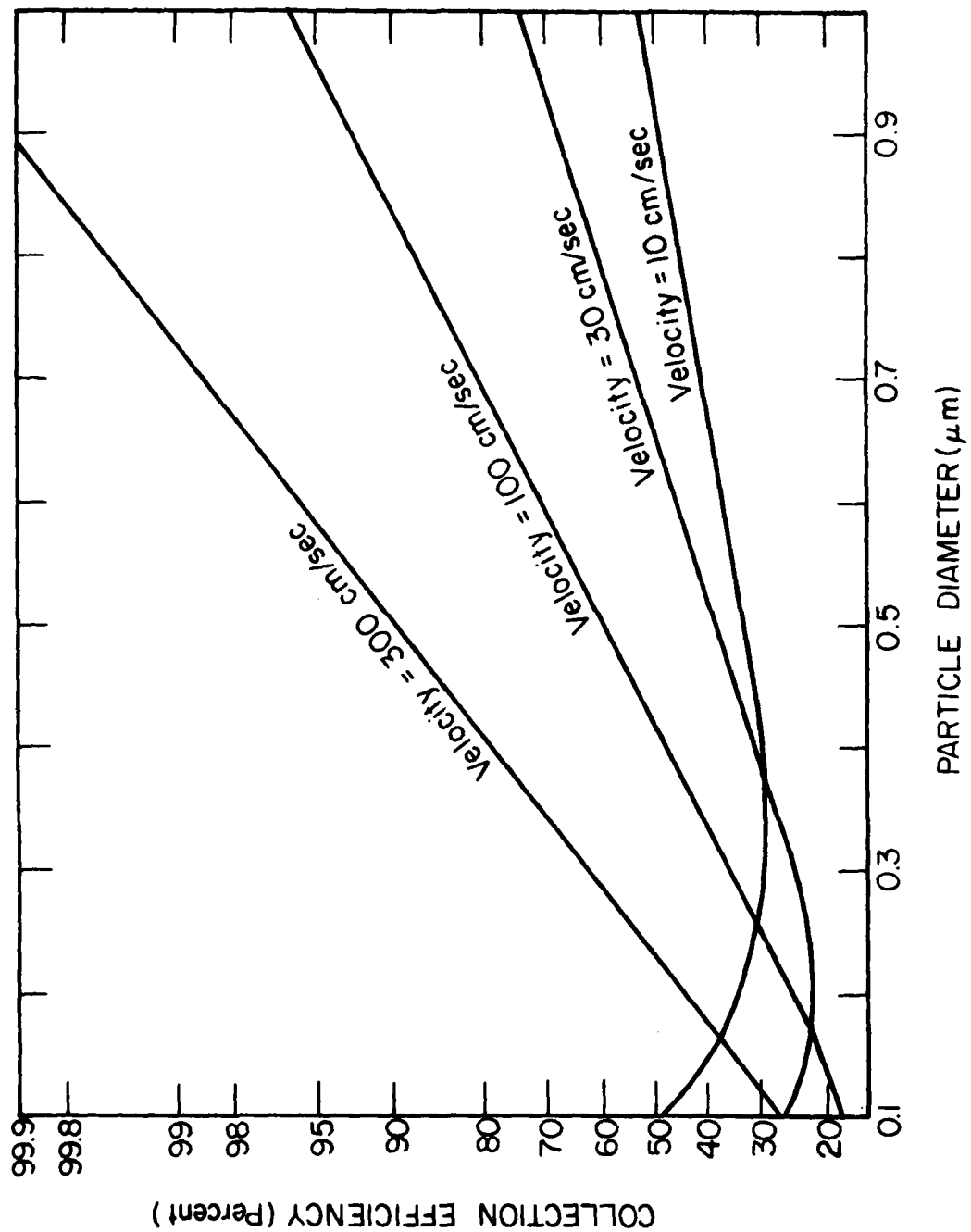
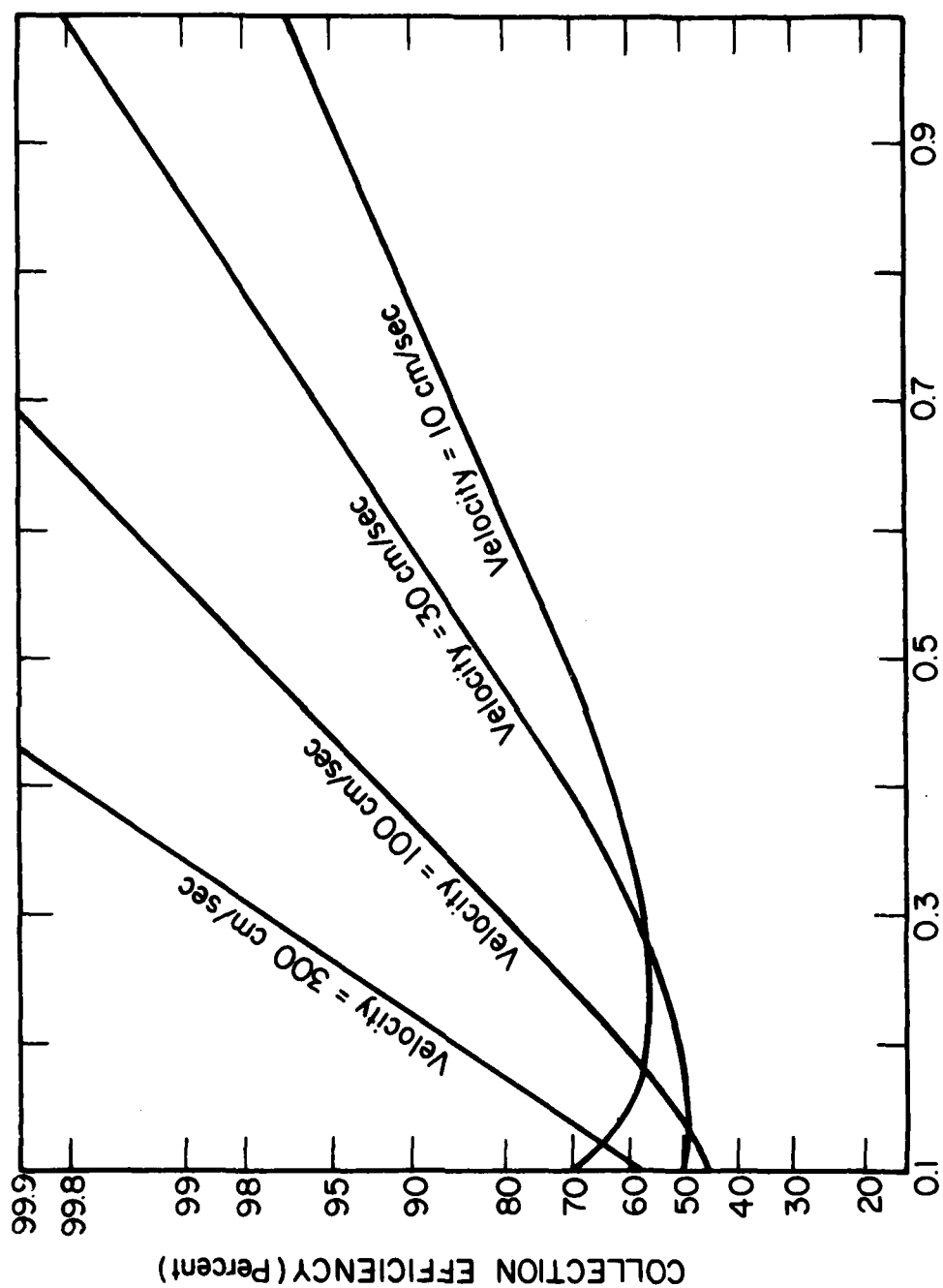


Figure 4. Collection Efficiency for Filter Media I and II



PARTICLE DIAMETER (μm)

Figure 5. Calculated Efficiency for Filter Media III

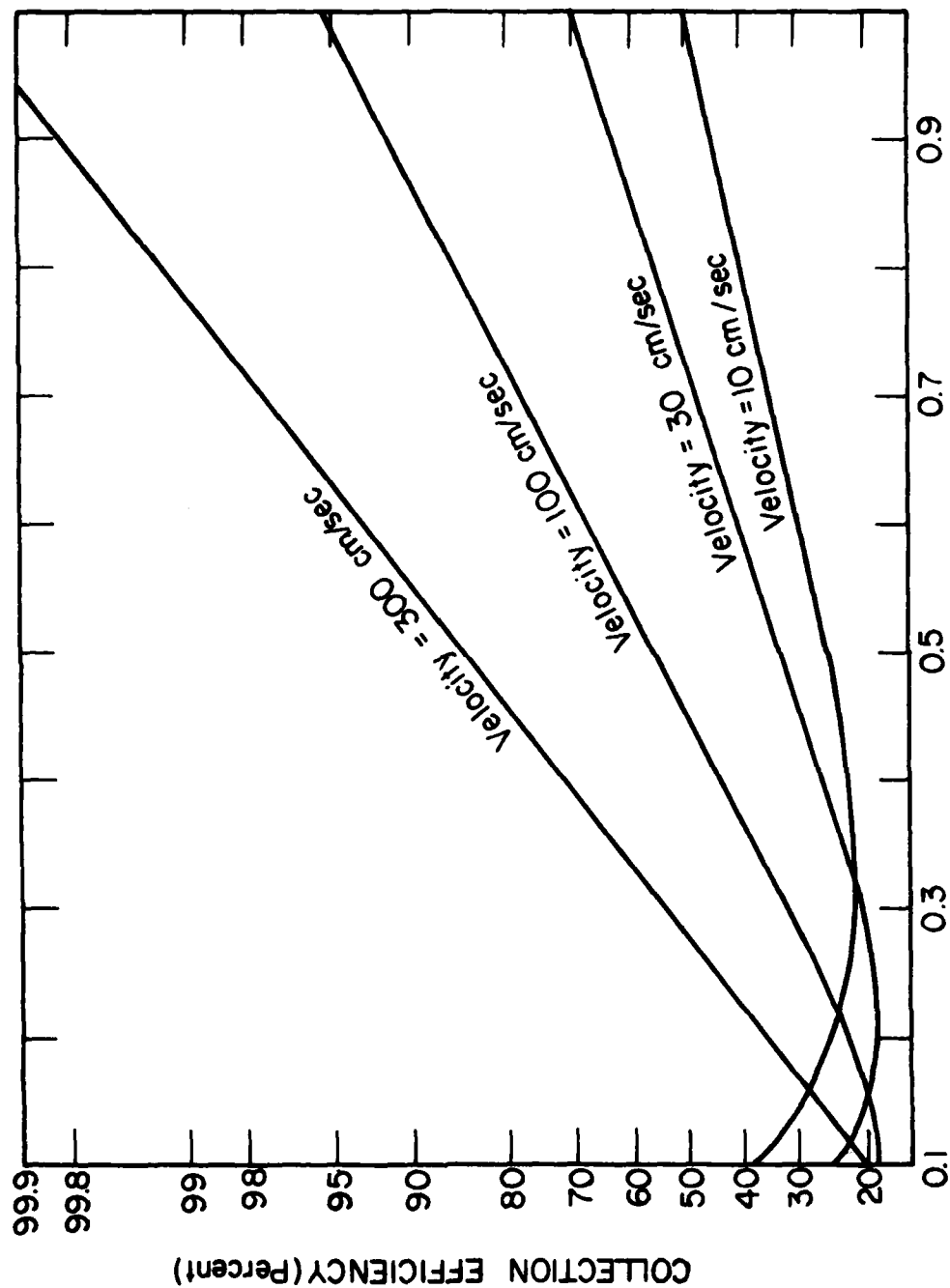


Figure 6. Collection Efficiency for Filter Media IV

TABLE 1 - FILTER MEDIA DESCRIPTION DATA

| | Filter | | | |
|---|---------|---------|--------|--------|
| | I | II | III | IV |
| OCF filter number | PF-3340 | PF-3360 | FM-004 | FM-011 |
| Media thickness (cm) | 3 | 3 | 0.8 | 0.8 |
| Weight/area (mg/cm ²) | 44 | 36 | 6.9 | 9.9 |
| Effective fiber diameter (μm) | 5.7 | 5.8 | 1.3 | 3.1 |
| Filter solidarity* (cm ² /cm ²) | 43 | 42 | 29 | 18 |
| Filter fiber volume fraction (cm ³ /cm ³) | 0.006 | 0.005 | 0.004 | 0.003 |
| Initial pressure drop (cm H ₂ O): | | | | |
| @ 10 cm/sec air flow | 0.24 | 0.19 | 0.75 | 0.18 |
| @ 100 cm/sec air flow | 2.4 | 1.9 | 7.5 | 1.8 |

* Filter solidarity is the ratio of total projected filter fiber cross sectional area to the filter mat face area.

TABLE 2 - IMPACTOR DATA FOR RUN 3

TEST DATE: 03/27/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 3
 FLOW RATE (LPM): 14
 SAMPLING TIME (MIN): 4.5

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 31 | -- | -- |
| 2 | 15 | -- | -- |
| 3 | 4.5 | 0.01 | 2 |
| 4 | 2.3 | 0.02 | 4 |
| 5 | 1.3 | 0.07 | 14 |
| 6 | 0.75 | 0.04 | 8 |
| 7 | 0.4 | 0.12 | 24 |
| FINAL | <0.4 | 0.23 | 47 |
| TOTAL | | 0.49 | |

MASS CONCENTRATION: 7.8 mg/m³

% BY WEIGHT < 1 μ DIAMETER: ~75%

TABLE 3 - IMPACTOR DATA FOR RUN 4

TEST DATE: 04/02/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 4
 FLOW RATE (LPM): 21
 SAMPLING TIME (MIN): 10

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 25 | -- | -- |
| 2 | 12 | -- | -- |
| 3 | 4.2 | 0.07 | 3 |
| 4 | 2.1 | 0.07 | 3 |
| 5 | 1.1 | 0.08 | 3 |
| 6 | 0.6 | 0.29 | 11 |
| 7 | 0.35 | 0.40 | 15 |
| FINAL | <0.35 | 1.71 | 65 |
| TOTAL | | 2.62 | |

MASS CONCENTRATION: 12.5 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~90%

TABLE 4 - IMPACTOR DATA FOR RUN 5

TEST DATE: 04/09/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 5
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 10

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | 0.04 | 5 |
| 2 | 9.5 | -- | -- |
| 3 | 3.8 | 0.04 | 5 |
| 4 | 1.8 | 0.06 | 7 |
| 5 | 1.0 | 0.09 | 11 |
| 6 | 0.51 | 0.09 | 11 |
| 7 | 0.27 | 0.07 | 9 |
| FINAL | <0.27 | 0.42 | 52 |
| TOTAL | | 0.81 | |

MASS CONCENTRATION: 2.9 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~72%

TABLE 5 - IMPACTOR DATA FOR RUN 6

TEST DATE: 04/11/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 6
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 15

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | -- | -- |
| 2 | 9.5 | 0.01 | 1 |
| 3 | 3.8 | 0.07 | 3 |
| 4 | 1.8 | 0.10 | 5 |
| 5 | 1.0 | 0.07 | 3 |
| 6 | 0.51 | 0.46 | 22 |
| 7 | 0.27 | 0.14 | 7 |
| FINAL | <0.27 | 1.27 | 60 |
| TOTAL | | 2.12 | |

MASS CONCENTRATION: 5.0 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~89%

TABLE 6 - IMPACTOR DATA FOR RUN 7

TEST DATE: 04/17/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 7
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 15

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | 0.04 | 1 |
| 2 | 9.5 | 0.08 | 2 |
| 3 | 3.8 | 0.08 | 2 |
| 4 | 1.8 | 0.05 | 1 |
| 5 | 1.0 | 0.06 | 2 |
| 6 | 0.51 | 0.49 | 14 |
| 7 | 0.27 | 0.55 | 15 |
| FINAL | <0.27 | 2.27 | 63 |
| TOTAL | | 3.62 | |

MASS CONCENTRATION: 8.6 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~92%

TABLE 7 - IMPACTOR DATA FOR RUN 8

TEST DATE: 04/19/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 8
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 30

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | 0.08 | 5 |
| 2 | 9.5 | 0.05 | 3 |
| 3 | 3.8 | 0.07 | 5 |
| 4 | 1.8 | 0.05 | 3 |
| 5 | 1.0 | 0.10 | 6 |
| 6 | 0.51 | 0.10 | 6 |
| 7 | 0.27 | 0.12 | 8 |
| FINAL | <0.27 | 0.98 | 63 |
| TOTAL | | 1.55 | |

MASS CONCENTRATION: 1.9 mg/m^3
 % BY WEIGHT < 1μ DIAMETER: ~77%

TABLE 8 - IMPACTOR DATA FOR RUN 9

TEST DATE: 04/20/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 9
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 30

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | 0.04 | 1 |
| 2 | 9.5 | 0.17 | 5 |
| 3 | 3.8 | 0.14 | 4 |
| 4 | 1.8 | 0.09 | 3 |
| 5 | 1.0 | 0.23 | 7 |
| 6 | 0.51 | 0.39 | 11 |
| 7 | 0.27 | 0.12 | 3 |
| FINAL | <0.27 | 2.32 | 66 |
| TOTAL | | 3.50 | |

MASS CONCENTRATION: 4.2 mg/m^3
 % BY WEIGHT < 1μ DIAMETER: ~80%

TABLE 9 - IMPACTOR DATA FOR RUN 11

TEST DATE: 05/14/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 11
 FLOW RATE (LPM): 28
 SAMPLING TIME (MIN): 30

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 23 | 0.0 | -- |
| 2 | 9.5 | 0.03 | 1 |
| 3 | 3.8 | 0.14 | 4 |
| 4 | 1.8 | 0.02 | 1 |
| 5 | 0.51 | 0.21 | 7 |
| 6 | 0.27 | 0.38 | 12 |
| 7 | <0.27 | 2.45 | 76 |
| FINAL | | 3.23 | |
| TOTAL | | | |

MASS CONCENTRATION: 3.8 mg/m^3
 % BY WEIGHT < 1μ DIAMETER: ~95%

TABLE 10 - IMPACTOR DATA FOR RUN 12

TEST DATE: 05/17/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 12
 FLOW RATE (LPM): 21
 SAMPLING TIME (MIN): 25

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 25 | 0.20 | 6 |
| 2 | 12 | 0.12 | 3 |
| 3 | 4.2 | 0.20 | 6 |
| 4 | 2.1 | 0.40 | 11 |
| 5 | 1.1 | 0.14 | 4 |
| 6 | 0.6 | 0.22 | 6 |
| 7 | 0.35 | 0.45 | 12 |
| FINAL | <0.35 | 1.90 | 52 |
| TOTAL | | 3.63 | |

MASS CONCENTRATION: 6.9 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~70%

TABLE 11 - IMPACTOR DATA FOR RUN 13

TEST DATE: 05/22/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: 13
 FLOW RATE (LPM): 14
 SAMPLING TIME (MIN): 50

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 31 | -- | -- |
| 2 | 15 | 0.03 | 1 |
| 3 | 4.5 | 0.01 | -- |
| 4 | 2.3 | 0.11 | 2 |
| 5 | 1.3 | 0.17 | 3 |
| 6 | 0.75 | 0.17 | 3 |
| 7 | 0.4 | 0.58 | 10 |
| FINAL | <0.4 | 4.46 | 81 |
| TOTAL | | 5.53 | |

MASS CONCENTRATION: 7.9 mg/m³
 % BY WEIGHT < 1 μ DIAMETER: ~92%

TABLE 12 - IMPACTOR DATA FOR RUN 14

TEST DATE: 05/21/79
 IMPACTOR TYPE: University of Washington
 FILTER RUN NUMBER: (Extra test run on aerosol from generator before dilution)
 FLOW RATE (LPM): 14
 SAMPLING TIME (MIN): 2

| IMPACTOR STAGE | STAGE CUT SIZE(μ m) | STAGE WEIGHT GAIN (mg) | % ON STAGE |
|-------------------|-----------------------------|---------------------------|---------------|
| 1 | 31 | 0 | -- |
| 2 | 15 | 0.02 | -- |
| 3 | 4.5 | 0.02 | -- |
| 4 | 2.3 | 0.05 | 1 |
| 5 | 1.3 | 0.21 | 4 |
| 6 | 0.75 | 0.27 | 5 |
| 7 | 0.4 | 0.55 | 11 |
| FINAL | <0.4 | 3.89 | 78 |
| TOTAL | | 5.01 | |

MASS CONCENTRATION: -- mg/m^3
 % BY WEIGHT < 1μ DIAMETER: ~91%

TABLE 13 - FILTER TEST DATA FOR RUN 1

| TEST DATE: | 03/07/79 | | | | | | | | | |
|---|-----------------------|-------------------------------------|-------|----------------------------|----------|----------|--|--|---------------------------|--|
| TEST RUN: | 1 | | | | | | | | | |
| TEST LENGTH (MIN): | 13 | | | | | | | | | |
| AVERAGE AEROSOL CONCENTRATION (mg/m ³): | ~3 | | | | | | | | | |
| FILTER MEDIA TYPE | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER GAIN (g) | | | TOTAL MASS LOADING (g/m ²) | | COLLECTION EFFICIENCY (%) | |
| | | INITIAL | FINAL | FILTER 1 | FILTER 2 | FILTER 3 | | | | |
| I | 3.0 | 6.1 | 7.9 | 0.0099 | -- | -- | 2.2 | | (1) | |
| II | 3.0 | 6.1 | 7.1 | 0.0033 | -- | -- | 0.7 | | (1) | |
| III | 3.0 | 38.6 | >60.0 | 0.0228 | -- | -- | 5.0 | | (1) | |
| IV | 3.0 | 8.1 | 13.0 | (2) | -- | -- | (2) | | (1) | |

(1) Not measured

(2) Filter media stuck in holder

TABLE 14 - FILTER TEST DATA FOR RUN 2

| TEST DATE: | 03/13/79 | | | | | | | | | |
|---|-----------------------|-------------------------------------|-------|-----------------------------------|----------|----------|--|--|---------------------------|--|
| TEST RUN: | 2 | | | | | | | | | |
| TEST LENGTH (MIN): | 15 | | | | | | | | | |
| AVERAGE AEROSOL CONCENTRATION (mg/m ³): | 2.4 | | | | | | | | | |
| FILTER MEDIA TYPE | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | | TOTAL MASS LOADING (g/m ²) | | COLLECTION EFFICIENCY (%) | |
| | | INITIAL | FINAL | FILTER 1 | FILTER 2 | FILTER 3 | | | | |
| I | 3.0 | 5.5 | 7.6 | 0.0125 | -- | -- | 2.7 | | 41 | |
| II | 3.0 | 7.6 | 9.6 | 0.0123 | -- | -- | 2.7 | | 41 | |
| III | 3.0 | 41.9 | ~60 | 0.0260 | -- | -- | 5.7 | | 86 | |
| IV | 3.0 | 9.0 | 22.3 | 0.0253 | -- | -- | 5.5 | | 82 | |

TABLE 15 - FILTER TEST DATA FOR RUN 3

TEST DATE: 03/29/79
 TEST RUN: 3
 TEST LENGTH (MIN): 12.5
 AVERAGE AEROSOL CONCENTRATION (mg/m³): ~13

| FILTER MEDIA TYPE (1) | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-----------------------|-----------------------|-------------------------------------|--------|-----------------------------------|----------|--|---------------------------|
| | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-III | 3.0 | 47.5 | >127.0 | 0.1047 | -- | 23 | ~75 |
| II-III | 3.0 | 54.9 | 127.0 | 0.0938 | -- | 20 | ~70 |
| I-IV | 3.0 | 12.4 | 46.9 | 0.1342 | -- | 29 | ~95 |
| II-IV | 3.0 | 16.8 | 42.2 | 0.1246 | -- | 27 | ~90 |

(1) Filter composite in order listed (air flow through I then III, etc.)

TABLE 16 - FILTER TEST DATA FOR RUN 4

| | | | | | | | | | |
|---|-----------------------|-------------------------------------|-------|----------------------------|----------|----------|--|---------------------------|--|
| TEST DATE: | | 04/02/79 | | | | | | | |
| TEST RUN: | | 4 | | | | | | | |
| TEST LENGTH (MIN): | | 12 | | | | | | | |
| AVERAGE AEROSOL CONCENTRATION (mg/m ³): | | 12.5 | | | | | | | |
| FILTER MEDIA TYPE | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER GAIN (g) | | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) | |
| | | INITIAL | FINAL | FILTER 1 | FILTER 2 | FILTER 3 | | | |
| I-I | 3.0 | 6.6 | 10.2 | 0.0679 | 0.0384 | -- | 23 | 84 | |
| II-II | 3.0 | 9.7 | 14.7 | 0.0657 | 0.0200 | -- | 19 | 68 | |
| I-II | 3.0 | 7.6 | 12.7 | 0.0725 | 0.0351 | -- | 24 | 85 | |
| II-I | 3.0 | 7.6 | 12.7 | 0.0612 | 0.0260 | -- | 19 | 69 | |

TABLE 17 - FILTER TEST DATA FOR RUNS 5, 6 and 7

TEST DATE: 04/09/79, 04/11/79, 04/17/79

TEST RUN: 5, 6, 7

TEST LENGTH (MIN): 60, 22, 25

AVERAGE AEROSOL CONCENTRATION (mg/m³): 2.9, 5.0, 8.6

| FILTER MEDIA TYPE | RUN # | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-------|-----------------------|-------------------------------------|-------|-----------------------------------|----------|--|---------------------------|
| | | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-Sample 1 | 5 | 3.0 | 4.2 | 14.4 | 0.1324 | -- | 29 | -- |
| " | 6 | 3.0 | 11.9 | 21.3 | 0.0937 | -- | 50 | -- |
| " | 7 | 3.0 | 18.0 | 65.8 | 0.2181 | -- | 97 | -- |
| I-Sample 2 | 5 | 3.0 | 4.6 | 13.5 | 0.1085 | -- | 24 | -- |
| " | 6 | 3.0 | 10.9 | 18.4 | 0.0813 | -- | 42 | -- |
| " | 7 | 3.0 | 16.3 | 52.1 | 0.1943 | -- | 84 | -- |
| I-Sample 3 | 5 | 3.0 | 4.3 | 15.4 | 0.1367 | -- | 30 | -- |
| " | 6 | 3.0 | 11.7 | 21.6 | 0.0986 | -- | 52 | -- |
| " | 7 | 3.0 | 17.5 | 68.3 | 0.0785 | -- | 69 | -- |
| I-Sample 4 | 5 | 3.0 | 4.2 | 13.8 | 0.1117 | -- | 24 | -- |
| " | 6 | 3.0 | 11.7 | 20.3 | 0.0845 | -- | 43 | -- |
| " | 7 | 3.0 | 17.3 | 58.9 | 0.3065 | -- | 110 | -- |

TABLE 18 - FILTER TEST DATA FOR RUNS 8, 9 and 10

TEST DATE: 04/19/79, 04/20/79, 04/26/79

TEST RUN: 8, 9, 10

TEST LENGTH (MIN): 60, 60, 120

AVERAGE AEROSOL CONCENTRATION (mg/m³): 1.9, 4.2, 4.8

| FILTER MEDIA TYPE | RUN # | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-------|-----------------------|-------------------------------------|-------|-----------------------------------|----------|--|---------------------------|
| | | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-I | 8 | 3.0 | 7.75 | 10.4 | 0.0348 | 0.0078 | 9 | |
| I-I | 9 | 3.0 | 9.9 | 12.2 | 0.1139 | 0.0380 | 43 | |
| I-I | 10 | 3.0 | 12.2 | 47.2 | 0.3896 | 0.0951 | 149 | |
| II-II | 8 | 3.0 | 9.4 | 11.8 | 0.0308 | 0.0103 | 9 | |
| II-II | 9 | 3.0 | 11.4 | 14.5 | 0.0995 | 0.0414 | 40 | |
| II-II | 10 | 3.0 | 13.0 | 56.9 | 0.3324 | 0.0878 | 132 | |
| I-II | 8 | 3.0 | 8.4 | 11.2 | 0.0286 | 0.0210 | 11 | |
| I-II | 9 | 3.0 | 10.7 | 13.0 | 0.1088 | 0.0688 | 37 | |
| I-II | 10 | 3.0 | 12.4 | 49.0 | 0.4047 | 0.1132 | 150 | |
| II-I | 8 | 3.0 | 7.0 | 9.4 | 0.0221 | 0.0093 | 7 | |
| II-I | 9 | 3.0 | 8.6 | 10.7 | 0.0892 | 0.0460 | 36 | |
| II-I | 10 | 3.0 | 10.2 | 34.8 | 0.3024 | 0.0966 | 124 | |

TABLE 19 - FILTER TEST DATA FOR RUN 11 and 12

TEST DATE:

05/14/79, 05/17/79

TEST RUN:

11, 12

TEST LENGTH (MIN):

60, 30

AVERAGE AEROSOL CONCENTRATION (mg/m³): 3.8, 6.9

| FILTER MEDIA TYPE | RUN # | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-------|-----------------------|-------------------------------------|-------|-----------------------------------|----------|--|---------------------------|
| | | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-I | 11 | 1.5 | 5.1 | 11.4 | 0.0926 | 0.0289 | -- | 27 |
| I-I | 12 | 1.5 | 10.7 | 13.4 | 0.0695 | 0.0103 | -- | 44 |
| I-I | 11 | 3.0 | 8.1 | 21.1 | 0.1625 | 0.0516 | -- | 48 |
| I-I | 12 | 3.0 | 19.4 | 34.3 | 0.1571 | 0.0431 | -- | 92 |
| V-I-I* | 11 | 3.0 | 8.1 | 17.5 | 0.0170 | 0.0836 | 0.0333 | 29 |
| V-I-I | 12 | 3.0 | 15.2 | 24.1 | 0.0513 | 0.0818 | 0.0218 | 63 |
| I-I | 11 | 4.5 | 15.7 | 41.1 | 0.1866 | 0.0665 | -- | 55 |
| I-I | 12 | 4.5 | 38.4 | 132.1 | 0.2826 | 0.5360 | -- | 129 |

* Suspect bonding agent on type V filter evaporated

TABLE 20 - FILTER TEST DATA FOR RUN 13

TEST DATE: 05/22/79
 TEST RUN: 13
 TEST LENGTH (MIN): 60
 AVERAGE AEROSOL CONCENTRATION (mg/m³): 7.9

| FILTER MEDIA TYPE | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-----------------------|-------------------------------------|-------|----------------------------|----------|--|---------------------------|
| | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-I | 1.5 | 4.8 | 11.9 | 0.1462 | 0.0407 | 41 | ~80 |
| I-I | 3.0 | 8.6 | 27.2 | 0.2870 | 0.0898 | 83 | ~80 |
| V-I-I | 3.0 | 7.6 | 20.6 | 0.0511 | 0.1364 | 60 | ? |
| I-IV | 1.5 | 6.6 | 63.5 | 0.1450 | 0.0823 | 50 | ~95 |

TABLE 21 - FILTER TEST DATA FOR RUN 14, 15 and 16

TEST DATE:

05/27/79

TEST RUN:

14, 15, 16

TEST LENGTH (MIN):

60, 60, 120

AVERAGE AEROSOL CONCENTRATION (mg/m³): 6.5, ~7, 7.4

| FILTER MEDIA TYPE | RUN # | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-------|-----------------------|-------------------------------------|-------|-----------------------------------|----------|--|---------------------------|
| | | | INITIAL | FINAL | FILTER 1 | FILTER 2 | | |
| I-I | 14 | 1.5 | 4.2 | 8.4 | 0.0646 | 0.0352 | 22 | |
| I-I | 15 | 1.5 | 7.6 | 11.9 | 0.1279 | 0.0455 | 60 | |
| I-I | 16 | 1.5 | 11.9 | 14.2 | 0.1109 | 0.0420 | 93 | |
| V-I-I | 14 | 3.0 | 7.6 | 17.0 | 0.0137 | 0.1265 | 42 | |
| V-I-I | 15 | 3.0 | 15.2 | 37.3 | 0.2830 | 0.2413 | 116 | |
| V-I-I | 16 | 3.0 | 34.0 | 85.1 | 0.0272 | 0.2602 | 191 | |
| I-I | 14 | 3.0 | -- | -- | 0.0864 | 0.0596 | 32 | 92 |
| I-I | 15 | 3.0 | 11.7 | 24.9 | 0.1494 | 0.0892 | 84 | |
| I-I | 16 | 3.0 | -- | -- | 0.1424 | 0.0923 | 136 | 90 |
| I-I | 14 | 1.5 | -- | -- | 0.0788 | 0.0280 | 23 | 67 |
| I-I | 15 | 1.5 | 7.6 | 11.4 | 0.1133 | 0.0322 | 55 | |
| I-I | 16 | 1.5 | -- | -- | 0.1367 | 0.0409 | 93 | 85 |

TABLE 22 - FILTER TEST DATA FOR RUN 17

TEST DATE: 06/01/79
 TEST RUN: 17
 TEST LENGTH (MIN): (Filter cleanability test)
 AVERAGE AEROSOL CONCENTRATION (mg/m³):

| FILTER MEDIA TYPE | FILTER VELOCITY (m/s) | PRESSURE DROP (cm H ₂ O) | | INDIVIDUAL FILTER WEIGHT GAIN (g) | | TOTAL MASS LOADING (g/m ²) | COLLECTION EFFICIENCY (%) |
|-------------------|-----------------------|-------------------------------------|----------|-----------------------------------|----------|--|---------------------------|
| | | INITIAL * | FINAL ** | FILTER 1 | FILTER 2 | FILTER 3 | |
| I-I | 1.5 | 17.8 | 6.1 | | | | |
| I-I | 3.0 | 33.8 | 9.7 | | | | |
| V-I-I | 3.0 | 94.0 | 15.2 | | | | |
| I-I | 3.0 | 49.5 | 9.1 | | | | |
| I-I | 1.5 | 21.1 | 5.8 | | | | |
| I-I | 3.0 | 48.5 | 10.2 | | | | |

* Before wash

** After wash

INITIAL DISTRIBUTION

| | |
|-----------------------------|---|
| DDC/DDA | 2 |
| HQ AFSC/DL W m | 1 |
| HQ AFSC/SD | 1 |
| HQ USAF/LEEV | 1 |
| HQ USAF/SGPA | 1 |
| OSAF/MIQ | 1 |
| OSAF/OI | 1 |
| AFIT/Library | 1 |
| AFIT/DE | 1 |
| EPA/ORD | 1 |
| HQ AFESC/DEV | 1 |
| USA Chief, R&D/EQ | 1 |
| USN Chief, R&D/EQ | 1 |
| OEHL/CC | 1 |
| USAFSAM/EDE | 2 |
| HQ AFISC | 2 |
| HQ AUL/LSE 71-249 | 1 |
| HQ USAFA/Library | 1 |
| HQ AFESC/RDV | 9 |
| HQ AFESC/TST | 2 |
| OL-AD, USAF OEHL | 1 |
| OUSDR&E | 1 |
| USAF Hospital, Wiesbaden | 1 |
| Environmental Engineering | |
| Consultants | 2 |
| HQ AFLC/MA | 1 |
| HQ AFLC/DE | 1 |
| HQ AFLC/SG | 1 |
| AMD/CC | 1 |
| USAFSAM/CC | 1 |
| AFAPL/CC | 1 |
| USAFRCE/CR | 1 |
| USAFRCE/ER | 1 |
| Naval Air Propulsion Center | 1 |
| AFIT/LSGM | 1 |
| USAFRCE/WR | 1 |
| NARF Code 64270 | 1 |
| NSWC Code G-51 | 1 |